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THE
PHYSICAL CONSTITUTION
OF
THE SUN.

THE PHYSICAL CONSTITUTION OF THE SUN.

A DISCOURSE

DELIVERED IN
THE SHELDONIAN THEATRE AT OXFORD,
BEFORE THE BRITISH ASSOCIATION,
JUNE 29, 1860:

WITH
AN APPENDIX ON THE PHENOMENA OBSERVED IN SPAIN
DURING THE ECLIPSE OF JULY 18.

BIBLIOTHECA BODLEIANA

BY
REV. ROBERT WALKER, M.A., F.R.S.,
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OF THE BRITISH ASSOCIATION.

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BIBLIOTHECA · BODLEIANA ·

TO THE LORD WROTTESLEY,
M.A., V.P.R.S., F.R.A.S.,
PRESIDENT OF THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

My dear Lord,

I received your permission to dedicate this little volume to your Lordship with very great pleasure. I am glad to have so favourable an opportunity of testifying my great respect to you, as President of the British Association; of expressing, as far as I may be competent to do so, my full appreciation of your scientific labours; of offering, on my own part and that of others, sincere thanks for your exertions in promoting the interests of science; and, further, of acknowledging the kindness and courtesy which I, in common with every one who has been brought into communication with your Lordship, have uniformly met with.

I have the honour to be,
My dear Lord,
Yours very faithfully,

ROBERT WALKER.

PREFACE.

A very few words are necessary, by way of introduction, to the accompanying discourse. It is printed in the form in which it was delivered, and very nearly verbatim from the original manuscript. A few alterations have been made, chiefly as corrections of expressions, and with the object of rendering the meaning more intelligible. The commencement of the part on the Magnetism of the Sun has been rewritten; and some slight additions have been made, in order to render that most interesting and important question a little clearer. The curves in Plate IV., from the Kew Observations, have been introduced from the paper read by General Sabine before the Royal Society in March last, and which has only very recently been published. That paper cannot be too strongly recommended to the careful reading of every one who is anxious for accurate information on that subject.

Sincere acknowledgments are due to General Sabine for the amount of information supplied by his papers, and for the advantage of being allowed to read his preface to the St. Helena Observations before it was published; and also to Mr. Warren De la Rue for the readiness with which he supplied most valuable particulars respecting his observations in Spain during the late solar eclipse. Extracts from his communication will be read in the Appendix.

ROBERT WALKER.

Oxford, Aug. 3, 1860.

THE SUN.

THE object of this discourse is to bring forward, as far as I may be able, the present state of our knowledge concerning the physical condition of the great central body of this our system. It is evident, therefore, that I shall borrow information from every source within my reach, and I shall effect my purpose if I succeed in gathering together that which is known in a clear and connected form.

There was a time when it would have seemed presumptuous to speculate on the condition of a body holding such a position in the universe of God. But *we* have learned that it is a fitting exercise of the reason with which we have been endowed, to endeavour to apprehend the conditions which have been impressed upon every part of the creation. We may thus rise up in some degree from the real and eternal laws which have been prescribed, to the fuller and clearer contemplation of Him who prescribed them. It is true that His works, even in their marvellous perfection, only faintly display the Infinite Perfection of their Maker; but by contemplating those perfections which are within our grasp, we reach onward to the more distant perceptions of that which is Perfect and Eternal, and thus we learn in some measure to desire the actual fruition of the Perfect itself (1).

First of all I would briefly call attention to that which may be regarded as absolutely known concerning the distance, size, weight, &c. of the Sun. The principal known facts are presented in the following Table (2) :—

		Miles.
Mean distance from the earth	=	95,308,650
Diameter	=	888,842
Volume	=	1,415,225 times volume of earth.
Weight	=	354,936 times weight of earth.
Density	=	·2543 times density of earth, or about ¼ of density of do.

		Days.	Hours.	Minutes.
Period of rotation round axis	=	25	8	9

Inclination of axis to plane of the earth's orbit = 7° 9′

Progressive motion in space = 154,185,000 miles per annum.

Although these facts do not teach us much on the subject in hand, they are important to our inquiry, and it will be necessary to refer to one or more of them.

To these facts it may be added, that the Sun is not a fixed point with regard to its own system. It is subject to the counterbalancing attractions of the various bodies of which it is the central power, and in consequence of their motions, as they are sometimes more on one side than the other, it has a motion of its own round the common centre of inertia of the system, but on account of the greatness of its mass this point is always within the volume of the body itself. It has been calculated that if all the planets were for a time on one side of the Sun, they would not be able by their united attractions to draw it to a distance from the centre of inertia equal to its own diameter. The Sun therefore has a sort of orbital motion round the centre of inertia of itself and its system of planets.

SPOTS ON THE SURFACE.

The rotation of the Sun round its axis, and the inclination of that axis, are, as it is well known, determined by the singular spots which are seen upon its surface. These remarkable appearances claim the first attention in every inquiry into the physical condition of the great centre of our system.

The earliest record of any observation of spots on the Sun's surface is from China. They appear to have been noticed in that country as early as A.D. 321 (3). Probably they were seen by the naked eye, when the Sun's brightness was dimmed by fog or light clouds. Under such circumstances they have been frequently seen in this country. There is some little doubt as to the earliest European observer. The discoveries of Galileo, and the invention of the telescope, naturally led to an examination of the Sun, and he himself observed spots not later than 1611. C. Scheiner claims to have seen them early in that year. Johan Fabricius (4) was the first to publish on the subject, but the spots were observed and noted down by Hariot at the end of 1610; although there is no record of any continuance of his observations, nor did he publish that which he saw. But this is not a question for our present consideration (5).

Early observers made little use of the spots, except to determine the period of rotation. The means of observation in their power did not enable them to make a minute examination, and many more important subjects engrossed their attention. An expression, however, of Dominique Cassini in 1671 must be especially noticed. He writes to this effect:—"The solar disc which we see is a luminous ocean surrounding the solid and dark nucleus of the Sun: tumultuous movements taking place in the luminous envelope, allow us from time to time to see the mountain summits of the non-luminous body of the Sun itself. They are the black nuclei in the centre of the solar spots."

Nothing further seems to have been noticed until the observations of Dr. Alexander Wilson, of Glasgow, in 1769 (6). He watched a spot as it moved from an edge to the centre of the Sun, and again as it passed away to disappear over the opposite edge. He remarked how the dark nucleus was surrounded by a dim shade or penumbra, which on one side of the centre becomes gradually narrower, and after passing the centre, becomes apparently wider on the side opposite. From this he inferred that the dark nucleus is a part of the dark body of the Sun itself, which is seen through a funnel-shaped excavation in *a luminous* atmosphere, and that the *penumbra* is formed by the deep declivities or side-walls of the funnel.

Bode, of Berlin (7), made similar and independent remarks a few years later. He assumed an additional cloudy vapour between the photosphere and the dark body of the Sun, in order to explain more clearly the appearances presented by the penumbra surrounding the spots.

But Sir William Herschel in 1779 was led by the visibility of a spot to the naked eye to enter into the subject, and his genius and power added largely to the knowledge of the ever-changing appearances of the Sun's surface. The careful examination of Herschel led to the assumption that the Sun consists of a central dense body, surrounded by three nearly concentric envelopes (8).

The *first* of these next to the central solid mass is a cloud-like vaporous covering, rising from the crust or darker surface—possibly acting by its elasticity to force passages through the outer envelopes. These will be only small pores or punctures when it acts feebly; but large in proportion as it acts with greater energy or with tempestuous violence. This first covering would be as it were an atmosphere to the Sun, and possibly clouds might form in it over the immediate surface as in an atmosphere; but they would appear to be suspended at least 300 miles above the body of the Sun. These have been supposed to be capable of protecting the immediate surface of the body from the heat which is produced in superior envelopes, and so may render it habitable by animated beings; but this notion is altogether untenable. The heat is so intense that no clouds, however dense, could intercept it; and further, as is remarked by Young (9), a heavy body at the surface of the Sun would fall through 450 feet in 1″; so that even if every other circumstance permitted, the weight of a human being would be nearly thirty times as great as upon the surface of the earth, and a man of moderate size would weigh above two tons. But we may well leave the question of the habitability of the Sun to the learned authors of the 'Plurality of Worlds,' and 'More Worlds than One."

Above this first and inner envelope of vapour or clouds there seems to be a *second*, which is the luminous envelope or photosphere. Herschel inclines to believe this to be a stratum of unconnected phosphoric clouds with uneven surfaces. This is subject to continual fluctuations, not only from the action of the inferior elastic vaporous envelope bursting through, and so presenting the varied spots with their jagged edges and re-entering angles, but also from peculiar agitations within itself. These agitations produce the tumultuary formation of what are called *faculæ*, furrows and projecting ridges, which are as it were the crests of luminous waves, and indicate the principal evolution of heat and light.

The *third* and outermost of the three solar envelopes is supposed to be cloudy and of imperfect transparency. Its existence has been considered as established by the mountain or flame-like forms which were observed especially during the total eclipse of July 8, 1842. These rose-coloured marginal protuberances had been noticed on the occasion of earlier total or annular eclipses, as, for instance, in 1706, as has been pointed out by Arago (10). But the eclipse of 1842 gave a very favourable opportunity for their examination; and they were observed not only by Arago, but by Laugier and Mauvais at Perpignan, Petit at Montpelier, Airy on the Supergo, Schumacher at Vienna, and by others, with a great diversity of telescopes, but in every case with uniformity of observation. The heights of these protuberances were such as would correspond to elevations of 40,000 miles. They cannot therefore be solid mountains, and hence are supposed to be undulations or protuberances in the *third envelope*, or masses of clouds illuminated and coloured by the subjacent photosphere. In such an eclipse, if there were no vaporous atmosphere around the Sun capable of reflecting light, the sky would appear totally dark, for the Moon has no atmosphere; but instead of darkness over the face of the sky, a bright ring or corona of light is seen concentric with the Sun, and fading gradually away. This was witnessed in 1842, and noticed by every observer.

The eclipse of July 28, 1851, was watched with great anxiety, and presented the same phenomena. Red cloud-like projections were gradually uncovered by the receding west limb of the Moon as that body continued its eastward course; and, on the other hand, disappeared on the opposite side as they were gradually covered by the advancing limb of the Moon. The shape of some of these ruby peach-red forms was seen to undergo rapid and sensible attractions during the continuance of the eclipse: one projection in particular appeared to rise straight up vertically from the edge of the disc and then suddenly to turn off at a right angle, just as a column of smoke is often seen to be drifted off horizontally, when it has attained a height sufficient to bring it into upper currents of wind. There were also seen, long, narrow, crimson-coloured bands, often detected at the edges, appearing as if resting against the margin of the Moon.

The eclipse of March 15, 1858, confirmed these appearances as far as the weather permitted observation; but we now wait with anxious interest to the eclipse which will be observed in Spain and Algiers on the 18th of July*.

A very different view, however, with regard to these rose-coloured forms has been put forward by no less an authority than that of our Corresponding Member, Dr. Lamont of Munich. He considers them as due to vaporous clouds which are formed by condensation within the cone of shadow, and which are drifted by currents of air outside of the shadow so as to be brought into the light of the Sun, or by "the motion of the earth on its axis, whereby the whole atmosphere, and consequently the masses of vapour suspended therein, are carried along over the Moon's disc from east to west."

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* See Appendix.

Dr. Lamont argues that the red or rose colours are simply the effect of the Sun's rays passing through vapours in our atmosphere, or perhaps above its ordinary limit. In confirmation of this view he appeals to experiment, and especially to a great number of reports and sketches; especially he brings forward a sketch made by Fearnley of the solar eclipse of the 28th of July, 1851, as observed by him at Rixhöft. This is exhibited in fig. 1, Pl. I., and is peculiarly characteristic. The form proper to clouds is distinctly pronounced, and extends far away from the Moon's edge, so that (to quote Lamont's words) "it seems impossible to look for the origin of the phenomenon any where but in our atmosphere." The report of Schmid, who observed the same eclipse at Rastenberg, is instructive. He perceived in the first seconds of totality, "several brighter places of imperfectly defined form, something like separate, white, very nebulously-blurred little clouds."

Lamont appeals to the observations of Dr. Moesta of the eclipse of November 30, 1853, to the south of Pisco in Peru, and of a commission of astronomers who observed the total eclipse of September 7, 1858, at Paranagua in Brazil.

I must refer to the paper of Lamont, which may be read in our language in the Philosophical Magazine for June 1860, for a fuller development of his arguments. The question may, however, be in some measure determined by comparing the observations of different persons at different positions. If the red prominences arise from anything so near the surface of the earth as cloudy vapour in our atmosphere, the change of a few miles would altogether change the appearances. Again, if vapours in an atmosphere produce the effect, we might expect other colours besides rose-red, as in the varied and varying tints of evening clouds.

But whatever view we adopt on this question, the existence of an atmosphere superior to the photosphere affords an easy explanation of the faculæ, which are strongly-marked, curved, or branching streaks more luminous than the rest of the apparent surface; and further, it affords a general explanation of that varied appearance which has been compared by some to the surface of mottled soap, but more elegantly by Sir J. Herschel, "to the slow subsidence of some flocculent chemical precipitate in a transparent fluid when viewed perpendicularly from above" (11).

But to return to the spots. Their general character has been mentioned. They vary in size from an almost imperceptible point or spot, to chasms of very large dimensions. A black nucleus, which is figured in the Cape Observations of Sir John Herschel, was found by careful measurement to be of such a magnitude, that if the earth had been thrown into the opening, there would have remained on either side a vacant space of more than 970 miles.

But these spots are continually undergoing the most remarkable changes amongst themselves, both in magnitude and form. Sometimes they break up and divide into two or more, and offer every indication of that extreme mobility which belongs to the fluid state, and of that exceedingly violent agitation which seems alone compatible with a gaseous state of matter.

The scale also of their internal movements is enormous. A single second of angular measure, as seen from the earth, corresponds on the Sun's disc to 461 miles; and a circle of this diameter, viz. nearly 167,000 square miles, is the least space distinctly discernible on the Sun as a visible area; and spots, whose diameter cannot be less than 45,000 miles, have altogether closed up in less than six weeks.

During the last few years every change, both in form and character, has been watched with the greatest diligence both by English and foreign observers. It were impossible, in a report like the present, to do justice to them all. But I ought not to omit the valuable contributions made by Mr. Dawes, who, by means of his admirable solar eye-piece (12), has been able to scrutinize the Sun with the greatest accuracy. One of the early results of Mr. Dawes's observations, is the determination of a violent whirling taking place in some of the spots. The drawings which Mr. Dawes made of one very remarkable case have been reproduced in several works on the subject; but as Mr. Dawes has kindly lent me his original drawing, they are re-engraved in figs. 2, 3, Pl. I., because they exhibit the rotation of the spot in a most distinct manner. The dates exhibit the change of position in the days noted. Among other observations which Mr. Dawes has communicated, I should notice one of the 22nd of last October (13), in which, in a large mass of bright streaks or faculæ, he saw "one bright streak forming the very edge of the Sun, and projecting irregularly beyond the circular contour of the edge, reminding him of a ridge of low hills often seen at the enlightened limb of the Moon." This observation seems important with reference to the question of the red prominences.

Among foreign observations, those of Father Secchi are very interesting: he has had very careful drawings made of all that he saw, especially on the 14th of March, 1858; and he speaks (14) of the *filamentous* aspect of the spot seen on that occasion; these filaments seemed like currents, and to describe spiral curves; also a portion of the nucleus was covered with a reddish veil much less luminous than the penumbra. This light cloud disappeared the next day, and was replaced by what seemed a tongue of the matter of the ordinary photosphere. This, he conceives, "may indicate some sensibly luminous matter in the envelope, which, casting itself into the nuclei, produces the appearance of clouds, and also the red protuberances seen in total solar eclipses." Secchi also gives measures of the depth of the spot above described, and makes it more than one-third of the radius of the earth. He adds, that he thinks some spots are deeper than the earth's radius.

The most diligent, however, of foreign observers, as to the appearances of the spots, is perhaps M. Chacornac, who has most carefully watched and drawn every appearance since March 1852. On one occasion (15) he observed a sudden transformation of the luminous part of the photosphere into dark parts; luminous bridges were seen crossing the spots, and then gradually becoming dark. As these luminous bridges darkened, they at the same time plunged into the deeper parts, and became covered with other luminous bridges which formed above them.

M. Chacornac is of opinion that this fact is established by all his observations, that *all the envelopes perceived* by astronomers through the openings of the photosphere may be regarded as *parts* of the photosphere. He remarks, that, "by the aid of a powerful telescope, the photosphere may be seen to dip in gradually, spots descend below the level of the luminous covering, and plunge, without breach of continuity, into the very deepest parts of their nuclei." "This dipping in or descending of the photosphere is a characteristic of the formation of a spot. The photosphere itself appears to be formed of fluffy cottony matter, held in suspension in a transparent fluid.

It covers the spots in certain phases with a glutinous appearance, which gives them some similitude to dough in a state of fermentation."

Again he says, "The phenomena which produce a spot act by intermittence, which may be described 'as a *central emission;*' then for fifteen or twenty minutes several small openings undergo enlargement, the parts of the photosphere in the neighbourhood begin to incline, and, as they grow dark, they plunge inward, just as a sheet of ice covered with snow would if melted by a hot liquid applied to the lower part."

Again: "Sometimes several streams of apparently incandescent matter are seen to start from the photosphere, and rush into the bottom of the spot. In a spot observed on March 11, 1859, M. Chacornac says that he imagined he saw the appearance of incandescent matter in a state of fusion, precipitating itself in torrents into the opening formed by the nucleus."

But I must refer for further descriptions to the most interesting memoirs of Chacornac in the 'Comptes Rendus.'

I ought not to leave this subject without alluding to the observations of Mr. Carrington, Mr. Hodgson, and Mr. Birt (16). They each confirm the observations alluded to. The two former gentlemen were fortunate enough to witness a very remarkable sudden outburst of light in a solar spot which they were watching on the 1st of September of last year. They describe the light as most dazzling to the protected eye, and as illuminating the upper edge of the adjacent spots and streaks like the edging of clouds at sunset.

It is evident that the changes which these spots are continually undergoing may give us much insight into the real condition of the great centre of our system. They are hence watched most diligently; and at our Kew Observatory the solar surface is most accurately photographed upon every favourable opportunity. I must not detail the ingenious contrivances which have been adopted to effect this object, but must content myself with simply referring to Pl. II. which presents copies of some of the results of the process. They exhibit to the eye the change of position of a considerable spot on different days. Let us hope that means will be adopted to continue these photoheliographs; and I for one rejoice that a recommendation has this day been made by the Committee of Section A, to supply the means for continuing and extending them.

But it must be remarked that the spots are not scattered over the whole of the surface (17). They are rarely seen in the equatorial zone itself from about 3° N. to 3° S., and they are entirely absent from the neighbourhood of the Poles. They are on the whole most abundant in a belt between 11° and 15° N. of the Equator, and more frequent in the North. Single spots have been found by Laugier as far as 40° N. Schwabe has seen *one* even in 50° N. Lahire describes one in 70° N.; but this must have been something very extraordinary—perhaps a planet. Mr. Carrington saw one in July 1859 in 44° S.

Mr. Carrington observed that, for two years preceding February 1856, the spots were confined to an equatorial belt, in no case passing the limits of 20° N. and 20° S.; but shortly after this epoch the spots seemed to forsake this space, and suddenly two new belts of disturbance abruptly commenced beyond the former limits. But from an examination of other observations, especially those of Sœmmering, there does not appear to be any law in such a change of distribution.

From this peculiar distribution of the spots, Sir J. Herschel inclines to the notion that the third or outermost envelope may resist the escape of heat at certain points, and so may give rise to currents in the solar atmosphere tending from the Poles to the Equator, similar to our trade-winds; and further, may in like manner cause calms near the Equator itself.

I commenced this notice of the spots by stating that the rotation of the Sun on its axis is determined by the motion of the spots. Their continual change of form renders it a somewhat difficult problem to determine the rotation accurately. There are, however, some spots which remain sufficiently permanent to be recognized precisely, not only from day to day, but in their recurrence. Thus Schwabe marked the same for eight returns in 1840. Nevertheless, astronomers differ as to the true period of rotation; even the same observer gives different results from different observations. Thus from one set of observations Laugier determines the period to be 24 days 6 hrs. 55 min.; from another, 26 days 11 hrs. 2 min. This difference is to be assigned to the individual or proper motions of the spots themselves, arising, as Mr. Carrington (18) observes, from drifts or currents on the surface of the photosphere. Mr. Carrington thinks that between certain parallels the drift is towards the Equator; in others, towards the Poles. The observations of Dr. Peters (19) coincide as to the existence of such drifts or currents, though his conclusions as to the direction of the drifts differ somewhat. But the currents may shift like our trades at different periods.

But of all observations on the spots of the Sun, those of Hofrath Schwabe, of Dessau, promise the most precise results. Schwabe has, with singular perseverance, watched the spots for thirty-four years, and has not only noted the character and changes which present themselves, but has recorded the numbers visible on each day for nearly 300 days in every year. The records of Schwabe are presented in the following Table (20), and it needs only a hasty view to perceive the regular law of recurrence of maximum and minimum every ten years. Thus, 1828, 1838, 1848, 1858, are years of the greatest number of spots, while 1833, 1843, 1853 are years of the least. The significance of this law is beyond our present speculation. It must, however, be regarded as a remarkable one; and when it is supported by continued observations and connected with other phenomena, it may lead us to some further knowledge concerning the physical condition of the Sun.

Solar Spots (Schwabe).

Year.	Groups.	Days free from Spots.	Days of Observation.
1826.	118	22	277
1827.	161	2	273
1828.	225	0	282
1829.	199	0	244
1830.	190	1	217
1831.	149	3	239
1832.	84	49	270
1833.	33	139	267
1834.	51	120	273
1835.	173	18	244
1836.	272	0	200
1837.	333	0	168
1838.	282	0	202
1839.	162	0	205
1840.	152	3	263
1841.	102	15	283
1842.	68	64	307
1843.	34	149	312
1844.	52	111	321
1845.	114	29	332
1846.	157	1	314
1847.	257	0	276
1848.	330	0	278
1849.	238	0	285
1850.	186	2	308
1851.	151	0	308
1852.	125	1	337
1853.	91	4	299
1854.	67	65	334
1855.	38	146	315
1856.	34	193	321
1857.	98	52	324
1858.	188	0	335
1859.	205	0	343

M. Wolf, of Berne, has, however, by carefully collecting all the records of remarkable appearances of spots from the first observations of Fabricius and Scheiner, deduced a rather different period from that of Schwabe. He estimates the period, from minimum to minimum, to be 11·11 years, or exactly nine periods in a century; the last year of each century, or 1700, 1800, &c., being a year of minimum. The maxima do not appear from Wolf's discussions to fall precisely at the middle year of the period, but about the 5th. In the 'Comptes Rendus' for January 1859, M. Wolf presents a curious mathematical formula, which expresses the number of years from the mean frequency of the spots in terms of the sines of angles dependent on the revolution of Venus, the Earth, Jupiter, and Saturn, round the Sun. The coefficients of the sines in the terms of this formula are in each case the mass of the planet divided by the square of its mean distance.

According to this formula, the spots are determined as to number and frequency by the position of these four planets: Jupiter preponderates and determines the length and height of the undulation of the curve; the action of Saturn shows itself by small variations; Venus and the Earth transform the line of simple undulation into a zigzag vibration. The form appears to be entirely empirical.

The question has naturally arisen, whether the appearance of spots on the Sun has any influence upon the climate of our globe. Sir W. Herschel (21) was disposed to think that years of abundant spots were remarkable for high temperatures and abundant harvests, while those of deficient spots were years of variable and uncertain weather. M. Gautier, who has examined the question with some care, inclines to the opposite conclusion; while Wolf, from an investigation of the records of Zurich from A.D. 1000 to 1850, considers that he has decisive evidence that "years rich in solar spots are in general drier and more fruitful, while years of few spots are wetter and more stormy."

The investigations of Dove, however, on the non-periodic variations of temperature, tend to show that "oppositions or contrary states of weather are always placed side by side in the same, or almost the same parallels of latitude." Thus if in Europe there is an abnormally severe winter, there will be a milder winter than usual in the same parallels in North America.

Schwabe (22) also holds the opinion that the spots have no influence whatever on the temperature of our globe. The records of the barometer and thermometer point to no effects on climate: if any effect at all, there are fewer clear days when the spots are most numerous.

THE HEAT OF THE SUN.

The effects which the Sun produces enter necessarily into every inquiry into the condition of its surface. It is the great source of Light and Heat to this our system. The latter of these will be most conveniently taken first.

The temperature at the visible surface must be far beyond that which we have any power of producing by the processes of art. The law of the decrease of radiant heat, viz. that of the inverse square of the distance, brings us to a most intense amount at the surface of the photosphere. Attempts have been made to estimate this, and the results have been expressed in such forms as these.

Suppose a cylinder of ice forty-five miles in diameter to be continually darted into the Sun with the velocity of light (200,000 miles per 1″), and that the water produced by its fusion were continually carried away, the heat now given off constantly by radiation would then be wholly expended in the liquefaction of the ice, on the *one* hand, so as to leave no radiant surplus; while, on the *other*, the actual temperature at the surface would undergo no diminution (23).

Professor Wm. Thomson calculates that the quantity of heat given out by the Sun in one year is equal to that which would be produced by the combustion of a stratum of coals all over the Sun fifty-five miles in thickness; or again, that it is equivalent in mechanical effect to the action of 7000 horse-power on every *square foot* of solar surface (24).

The observations of Father Secchi have resolved a very interesting question as to the relative temperatures of different portions of the solar disc. It appears from his most careful measurements that the equatoreal regions are hotter than the polar. Secchi extended his observations through different periods of the year, in order to prove that no portion of the effect could be ascribed to the absorption of the terrestrial atmosphere. The Table presents some of the measurements of Secchi reduced to a similar form for the sake of simplicity (the periods of the year are given) (25).

Heat of Sun's Disc (Secchi).

March, 1852.		May, 1852.	
Position.	Temp.	Position.	Temp.
+14′·96	57·39	+14′·5	65·00
+11·31	88·81	+10·1	78·07
		+ 6·3	92·30
+ 1·51	99·48	+ 3·0	94·30
		+ 0·5	97·30
−10·9	81·32	− 8·5	80·07
		−12·0	72·30
−14·88	54·34	−14·5	50·00

But how is the amount of heat which is continually given off as continually supplied? This is a question of no small interest. The various theories that have been proposed to answer this question may be regarded as a combination of one or other of the following, which may be thus considered:—

1. First, then, some have advanced the notion that the Sun is a heated body, made hot at the creation, and gradually giving out heat. This is utterly untenable. It can be demonstrated, upon every possible supposition as to the materials of the Sun, that at the present rate of emission of heat, the Sun would become cold in a very short time, possibly even in two or three minutes. Pouillet calculates that, even assuming the specific heat of the Sun as high as that of water, its temperature must decrease 20°·4 F. annually, unless there should be some supply.

2. It has been advanced that the heat is due to chemical action among the particles of its mass, or, in simpler language, that the Sun is a *great fire*. But then it is necessary to find fuel for the fire or the materials of combustion. And then, further, there must be some products from combustion. These, if gaseous, would rise to such an amount as to check the necessary supply; or, if solid, a liquid would choke the fire, so that any combustion would be extinct in a few minutes. If, then, the Sun be a burning mass, it must be much more analogous to burning gunpowder than to a fire burning, but then it would rapidly and gradually diminish. It would be entirely or nearly burnt away altogether in the space of 5800 years.

3. A third supposition is, in truth, very much the same as the chemical theory, and is open to the same

objections,—I mean that which ascribes the heat to currents of electricity. Electricity requires a supply either of matter or fire to maintain its action. The electrical theory, with regard to the Sun's heat, in the present state of our knowledge of electricity, seems much the same as a confession of ignorance.

4. A fourth theory suggests that the heat of the Sun, as the internal heat of the earth, arises from the compression of matter. It supposes that the Sun, and all the bodies of our system, were once only nebulous matter; but they have become condensed into their present form by the mutual attraction of their particles, and this condensation is necessarily accompanied by heat. Helmholtz calculates that the mechanical force of this our system, which has been converted into heat by this condensation, is sufficient to raise a mass of water equal in size to the Sun and planets to 28,000,000° C. We may form some notion of the intensity of this, by remembering that platinum is fused by the oxyhydrogen blowpipe at 2000° C.; or thus, if the mass of the entire system were pure coal, the combustion of the whole would only generate the 350th part of the heat which is due to the condensation.

Some of those who adopt this theory, suppose, further, that the Sun is still undergoing condensation, and it is estimated that an amount of condensation which would diminish the diameter by only the 10,000th part would suffice to restore the heat given off in 2000 years. This diminution would only affect the diameter of the solid nucleus; the weight of the mass would continue invariable; the gaseous envelope or photosphere might retain the same apparent volume.

5. One more theory has of late attracted much attention. It is in some measure an advance upon the fanciful conjectures of Newton and Buffon, that comets might possibly be the aliment of the Sun. It is this; that *meteoric matter* supplies a source of dynamical energy equivalent to the amount of heat emitted. This theory was first brought forward by Mr. Waterston at the Meeting of our Association at Hull, in 1853. Mr. Waterston then advanced as a speculation, that solar heat is produced by the impact of meteors falling from extraplanetary spaces and striking the surface of the Sun with velocities acquired by its attraction. Professor Wm. Thomson, in a paper read to the Royal Society of Edinburgh in 1854, has taken up this speculation, and has entered minutely into the calculations requisite to establish Mr. Waterston's hypothesis. Basing his calculations upon the valuable experiments of Joule and Rankine, but especially upon the experiments of Mr. Joule, which determine in foot-pounds the value of each degree of temperature, Professor Thomson shows that the theory of meteors supplying the Sun with sufficient force is perfectly conceivable. In the number of meteors within the orbit of the earth, there are stores of energy for future sun-light and sun-heat. We see these stores in the zodiacal light, which is, to

quote the words of Herschel, "an illuminated shower, or rather tornado of stones." The inner parts of this tornado are always getting caught in the Sun's atmosphere and drawn into his mass by gravitation.

But Professor Thomson's views are best expressed in his own words. "The source of energy from which solar heat is derived is undoubtedly meteoric. It is not any intrinsic energy in the meteors themselves, EITHER POTENTIAL, as of mutual gravitation, or chemical affinities among their elements, OR ACTUAL, as of relative motions among them. It is altogether dependent on mutual relations between these bodies and the Sun. A portion of it, although very probably not an appreciable portion, is that of motions relative to the Sun, and of independent origin. The principal source, *perhaps* the sole efficient source, is in bodies circulating round the Sun at present inside the earth's orbit, and probably seen in the sun-light by us, as the zodiacal light. . . . . The store of energy for future sun-light is at present *partly dynamical*, that of the motions of these bodies round the Sun, and *partly potential*, that of their gravitation towards the Sun. This latter is gradually being spent, half against the resisting medium, and half in causing a continuous increase of the former. Each meteor thus goes on moving faster and faster, and getting nearer and nearer the centre, until some time, very suddenly, it gets so much entangled in the solar atmosphere as to begin to lose velocity. In a few seconds more it is at rest on the Sun's surface, and the energy given up is vibrated in a minute or two across the district where it was gathered during so many ages, ultimately to penetrate, as light, the remotest regions of space."

An obvious objection to this somewhat startling hypothesis is, that, according to Mr. Waterston's theory, there must be, as observed by Herschel (26), a perpetual battery upon the solar surface requiring a weight of matter equal to 5 lbs. to be delivered every hour upon every square foot of surface, with a velocity of 390 miles per 1″; so that the whole solid surface would be covered with solid matter, of the density of granite, to the depth of 12 feet per annum. Professor Thomson's theory seems to suppose the effect to be rather that of nebulous matter acting on the external envelope or photosphere; but this, as observed by the same great authority, is really not a different supposition, for "the matter, whether pulverulent, liquid, or gaseous, must condense as matter, and would require a deposit equal to nearly double of that necessary on Waterston's hypothesis, viz. 24 feet of granite per annum, and this would amount to 1 mile in 220 years; so that the Sun's diameter and weight must be increasing, which is contrary to observation."

This objection seems to be fatal to this hypothesis, unless it be asserted that the matter of the meteors is actually converted into light and heat. If a degree of heat can be shown, not only to be equivalent to so much mechanical effect, but that the two are convertible, then the efforts necessary to maintain such vast supplies of heat and light, although it be manifested only in a vibratory motion communicated to an elastic medium, must produce an exhaustion which requires a regular and continuous restoration. In this view the theory suggests a beautiful compensation. But we are not yet prepared to admit *the convertibility of matter and force.*

Professor Thomson, in his most interesting paper, makes one calculation, to which we must, I think, demur absolutely. He estimates that the amount of meteoric matter existing in the zodiacal nebula is not sufficient to maintain the necessary supply for more than 300,000 years. This estimate is indeed quite sufficient to allay the apprehensions of the present generation. It is not quite so alarming as a calculation which was made some thirty-five years ago, that the coal of England, at the then rate of consumption (and it has somewhat increased since), would be all exhausted in less than thirty years. But there can be no fear about the Sun. He who made it has taken good care that it shall not die out until He refashions it. In fact, the theory of Professor Thomson, if carried on to its full extent, seems to provide fresh supplies for ever. Every motion produces an effect. No vibration is lost. The meteor which is taken into the Sun goes out again in the form of heat and light; so many foot-pounds come forth as so many degrees of heat, and these go forth each to do its own duty. Some of them convey light and warmth to the earth, and impart vitality and growth to the vegetation on its surface, supplying food for man and the various animals, as well as joy and gladness; and those that apparently pass away into that which we call empty space, are doing something,—possibly refashioning the medium which pervades the interplanetary spaces, and preparing it to form nebulous matter, and so supply fresh pabulum for the zodiacal light. And may not that progressive motion of the Sun, which we now conceive to be simply rectilinear, be really a portion of a large curve or orbit, in which the Sun is designed to travel into fresh pastures, to search for fresh aliment to enable it to fulfil its task?

I ought not to quit this theory without noticing a very interesting calculation of Mr. Waterston's, published in the 'Proceedings' of the Astronomical Society(27), on the heat which would be engendered by the possible fall of a meteor into the Sun, in order to explain that sudden outburst of light on the solar surface observed by Mr. Carrington and Mr. Hodgson in September last. He gives also, in the same paper, a mode by which the absolute temperature of the solar surface may be determined by thermometric observations.

Piazzi Smyth (28) has also entered into the question of the possibility of the existence of one large planet, or a zone of small ones, circulating round the Sun, at distances less than half the distance of Mercury, and shows that this question is quite independent of the theory of Waterston and Thomson. On the dynamical theory of heat, a planet, or planetoid falling into the Sun, would, from the conversion of its previous mechanical energy, give out such an awful blaze as would scorch up in a moment all the inferior planets, and probably the earth itself, and all that is upon it. But Physical Astronomy teaches us that a planet once revolving round the Sun, even at so small a distance as 18,000,000 miles, cannot become entangled with the atmosphere of the Sun until a distance of time practically infinite. The zone of meteors which supply the Sun must be much nearer. There must be an infinite number of such bodies, increasing in number up to the solar atmosphere itself; such as, indeed, we may almost fancy we can see on observing the steady increase of the zodiacal light with every step of its apparent approach to the solar centre. Mr. Piazzi Smyth then calculates the velocity with which the meteors (if indeed they are meteors) that produced the phenomena observed by Messrs. Carrington and Hodgson must have been revolving before they became entangled in the solar atmosphere.

Mr. Vaughan, of Cincinnati (29), has broached a theory which is somewhat different from those I have noticed, which may be thus stated:—"That the Sun, by its great superiority of attraction, draws into itself a great amount of the ether of space; it becomes necessarily the focus in which this ether must display its luciferous properties. The luminosity and the heat are due to the chemical action which may be expected to take place in the etherial fluid as it is condensed around the great sphere." Again, he says, "The etherial fluid is so much rarefied in the interplanetary domain, that no chemical changes can take place between its elements, except where it is collected around the largest spheres, and compressed by their powerful attraction. In obedience to the law of gravitation, which exerts universal control over all matter, atmospheres of the etherial fluid are collected round the earth and the other large planets; but they are not sufficiently dense for chemical action, except in cases where they receive an additional pressure from meteoric stones sweeping through them with furious rapidity."

It is right to give this hypothesis in Mr. Vaughan's own words; but the observations made upon the other theories render further comment unnecessary. It is, in fact, only a modification of the hypotheses already examined*.

THE LIGHT OF THE SUN.

Every inquiry into the source of the heat of the Sun involves of necessity the consideration of its *Light*. Solar Light and Solar Heat accompany each other. Light is *as* necessary to every process of vegetation or of life *as* warmth.

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* A perfectly novel theory was, I am informed, brought forward before the Royal Society of Edinburgh only a few weeks since, which ascribes the heat and light of the Sun to myriads of phosphorescent animalcules!

It was difficult to form adequate conceptions of the amount of heat emitted by the great centre of heat; it is much more difficult to estimate the amount of light which is spread abroad by the great luminary of our system.

Comparisons have been made between the light of the Sun received on a small portion of the surface of the earth with the most intense lights which art can produce. Messrs. Fizeau and Foucault (30) concentrated by lenses the light of the Sun, the light of the voltaic arc, and the oxyhydrogen light, and estimated their relative effects by their action upon a photographic plate. The results of their experiments are expressed in the following Table, by which it will be at once seen how very superior the light of the Sun is.

Intensity of Light.

Light of Sun, say	1000
Voltaic arc from 46 small pair of Bunsen's =	285
Ditto from 46 large pair	385
Oxyhydrogen lime-light	6·85

The inferiority of the oxyhydrogen has been made manifest by projecting it on the disc of the Sun, when it appears no more than a black spot upon the surface.

Mr. Ponton (31) has determined that a small surface illuminated by mean solar light is 444 times brighter than when illuminated by a moderator lamp, and 1560 times brighter than when illuminated by a wax candle (short sixes), the artificial light being in both instances placed at 2 inches distance from the illuminated surface. And further, that three electric lights, each equal to 520 wax candles, will render a small surface as bright as when illuminated by mean sunshine. He has hence calculated that a stratum over the surface of the Sun 94 feet thick, and embracing 138,825 layers of flame, each equal in brightness to the electric light, would give an amount of illumination equal in quantity and intensity to that which is given out by the Sun.

Mr. Vaughan, of Cincinnati, presented to this Association, in 1847, a curious calculation founded on the photometrical estimates of Euler and Wollaston, that the rays of the Sun have upon any small surface on the earth an illuminating power = 14,000 wax candles at 1 foot distance, and hence by applying the law of the inverse square of the distance, this effect would be produced by

3500,000000,000000,000000,000000

wax candles at the distance of the Sun; an amount of light (he observes), which could scarcely be produced by the combustion of 700 globes of tallow each equal to the earth in volume.

These estimates give only the light which is imparted to a small surface on the earth; but not only is every portion of the earth which is turned toward the Sun receiving such an amount continually, but light is spread out in all directions from the Sun into boundless space. And how is this unceasing effect maintained? It would seem altogether impossible that light can be the effect of a continued emission of corpuscles. What an expenditure of force to project such unceasing spreading streams! But without entering upon the question as to the true theory of light, we encounter the idea of ceaseless activity upon the solar surface; a *motion* is produced, whether it be a motion of the translation of a molecule, or that of a vibration of an elastic ether—a motion is produced which is felt upon every portion of the earth that is turned towards it—upon the illuminated surface of every planet and satellite of our system, and by them reflected to our earth and spread out in every direction; and further, a motion which carries tidings of the existence of its source to the remotest known star.

And what becomes of this motion? Where does it stop? We only know this, that it is not lost—it cannot stop of itself—it must do its work; and we are sure, upon dynamical principles, that its work *is* done.

It has been stated by Arago (32) that the light of the Sun is essentially different from that which radiates from an incandescent body, because even that which proceeds from its margin, and comes to us therefore in a very oblique direction, shows no trace of polarization. It must therefore, according to his view, proceed from a gaseous self-luminous envelope.

There is reason to question (as Herschel does) (33) the correctness of this conclusion; as also another which was made by the same eminent philosopher, as to the relative intensity of the light from the centre and the edge of the disc. Arago was led by means of the polariscope to assert that the light is not greater at the centre than at the edges. This assertion was contrary to the opinion of former physicists, especially Bouguer and Laplace; and it has been recently established by M. Chacornac, that there is a decided difference between the light from the centre and from the edge. Chacornac has proved, as stated in a paper in the 'Comptes Rendus' of last November, that the central part of the Sun's disc has a sensibly uniform brightness for a distance from the centre of about $\frac{3}{10}$ths of its radius. The light then diminishes, and the brightness of the centre surpasses that of a point about half the radius from the centre by $\frac{1}{15}$th part of itself.

He also shows that this result is consistent with the supposition that the Sun is of uniform brightness, but surrounded by a homogeneous atmosphere of the thickness of half the radius, which has a coefficient of extinction expressed by 0·511, or about $\frac{1}{2}$.

Professor James Forbes (34) has, however, shown that the light which proceeds from the edge, although not of the same intensity as that which emanates from the centre, is yet homogeneous with it in its nature. By forming a prismatic spectrum of the light which proceeded exclusively from the edge during a solar eclipse in 1836, he found that it was perfectly identical, in respect to the number and position of the black lines traversing it, with the spectrum formed by rays from the whole surface.

MAGNETIC INFLUENCE.

But I must now pass on to phenomena less dazzling than those of Light and Heat, but which, being due to a more subtle influence of the Sun, may, perhaps, lead onward to a better knowledge of its true constitution.

It is well known that a compass needle does not point true north in every part of the earth's surface, but that it deviates in its direction in different places, and in many, as in our own country, to a very considerable amount. This deviation of the needle from the true geographical meridian was formerly called the *variation,* but now that we know that every estimate connected with the position of the needle is continually varying, it is more fitly called the *declination.* In England this declination had in the year 1815 attained to an amount of 24° 27′ to the West of the true meridian; before that period it was gradually increasing, and since that it has been progressively diminishing, so as to be at present somewhere about 21°. But besides this gradual *annual* change, the needle, if delicately suspended in a horizontal position, is observed to make a *daily* excursion from its mean place, and to move to and fro with great regularity, apparently following the Sun. This motion of the needle was soon observed to be regulated in every locality by *solar* time. It was also observed that in Europe the excursion is more extensive in summer than in winter. It was therefore natural to presume from these observations that this motion of the needle is due to thermic action producing thermo-electric currents on the surface of the earth, or at least affecting the magnetism of the earth. It has, however, been clearly established that the thermal action of the Sun has no influence whatever on this *diurnal motion* of the needle.

And here I must for a moment turn aside to remind you that our knowledge on this subject is mainly due to him who, with so much labour, skill, and acuteness, superintended the reduction of the mass of observations which were made at the instance of the British Association and of the Royal Society. It is well known to all who are acquainted with the Transactions of this Association, that my friend and predecessor in the honourable office of your General Secretary, in conjunction with Sir J. Herschel, Dr. Lloyd, Dr. Whewell, Mr. Airy, Dean Peacock, and others (whose names will be ever honoured in the history of the British Association and of British Science), brought forward at the Meeting in Newcastle in 1838 (35), the importance of instituting regular magnetic observations in different parts of the globe. Gauss had propounded his theory of magnetism. Hourly observations were made at Göttingen. Appeals were made to the most powerful states of the civilized world to cooperate in simultaneous observations. The Government of this country, under the united influence of the Royal Society and the British Association, established Magnetic Observatories in the most important positions in the wide dominions of England. These Observatories were furnished with the best instruments that could then be supplied, under the superintendence of a most competent Committee. Observations were carefully and regularly made upon a prescribed plan, and soon a mass of figures accumulated from different quarters. These were arranged and reduced under the direction of General Sabine; and one of the great results deduced is this, that although the Sun has a decided influence upon the magnetic needle, yet this influence is *not* connected with the *heat* which emanates from it.

This result is most clearly brought out in papers addressed by General Sabine to the Royal Society, and published in the Transactions (36); and it was also set forth in a most able report made to this Association when assembled at Liverpool (37). The conclusions announced in the report made at Liverpool, have been confirmed by further examination of other observations; but in order to point out more distinctly the action of the Sun as independent of its heat, it is necessary to collect into one view the various points that have been determined.

I. First of all, then, with regard to the daily excursion of the needle just noticed: it is established by a careful discussion of the observations, that this excursion becomes the greatest in Europe *before* the period of the greatest summer heat; and further, the greatest excursions precede the period when the variations of temperature in the course of the day are the greatest.

This excursion then, or diurnal motion, or to speak more accurately, the *diurnal variation,* is not regulated by increase of heat; but this point is decided absolutely by the fact, which is most clearly ascertained, that these greatest excursions take place at the same period of the year in places widely dissimilar in geographical position and relation of climate.

These points may be made distinct to the eye by a graphical representation. Thus, if the horizontal broken line in fig. 1, Pl. III. be taken to represent the mean or normal line of the declination during the day, the curved line will exhibit the annual mean of the *diurnal* deflection of the needle during the different hours. The north end of the needle will begin to move eastward during the early morning hours; it will arrive at its extreme easterly elongation between 7 and 8 in the morning; it will then begin to move westward, reaching its extreme westerly elongation somewhere between 1 to 2 P.M., and then begin to return in the easterly direction. This may be taken as a type of that which occurs at every part of the globe; for although there appear to be some differences as to the precise character of the excursions in the observations made in different localities (as for example, in some places an interruption in the nocturnal progression), yet when all disturbing influences are eliminated, the diurnal variation is seen to be of the character of a simple excursion, as represented (38). But a further examination leads to the conclusion that the amount of this diurnal variation is different in different portions of the year; and if similar curves were laid down for every month, it would be seen that they at once "separate into two well-characterized groups, one consisting of the six months when the Sun is north of the equinoctial line, and the other of the six months when he is south of that line. This is found to be the case alike at stations within the tropics, and at stations in the temperate zone, and not in one hemisphere only, but in both hemispheres"(39).

Thus, "in every case the six months from April to September, and the six months from October to March, forming the two distinct groups, may be represented by mean *semiannual* lines, from which the individual months differ comparatively very slightly, but which exhibit very marked distinctive characters, essentially the same in all varieties of geographical position."

Fig. 2, Pl. III. will present this fact clearly, where the red curve exhibits the diurnal variation from the vernal to the autumnal equinox, and the blue exhibits the variation for the other half of the year, the black line being the annual mean, as in fig. 1.

Curves very similar to this are derived from observations made at Toronto in 43° North latitude, and at Hobarton in 43° South latitude—with this natural difference, that as Hobarton is below the magnetic equator, the diurnal motion is westerly in the morning and easterly in the afternoon. Now let it be remembered that the summer of Toronto is the winter at Hobarton, and that yet we have similar affections of the needle at the same periods of the year, and at the same hours of local time. Further, also, it is found that there are the same results at St. Helena, situated within the tropics, where the distinction of summer and winter almost ceases. The same results come out from the discussion of observations made at the Cape of Good Hope; of the Russian observations at Pekin, which have been carefully reduced upon a uniform plan under the direction of General Sabine, and also of the records made by the instruments at Kew (40).

This most remarkable fact is made very clear by a single inspection of Pl. IV. (41), where the annual mean of the solar diurnal variation (the black curve in fig. 2, Pl. III.) is taken as the horizontal line, and the semiannual curves are referred to that as an axis, the red and the blue curves corresponding in each figure.

The mere inspection of these figures is sufficient to show that there must be some other cause for the phenomena than variations of temperature, and at the same time to give evidence of the influence of the Sun in producing this diurnal variation of the magnetic needle, but an influence not exerted by the effects of heat upon the earth.

It should be mentioned here that the same fact is obtained from the independent reduction of observations at Makerstoun, by Mr. Broun (42). By a very different mode of examination, Mr. Broun also has established that the thermal action of the Sun does *not* influence the motion of the needle.

II. Secondly, we have another proof derived from these observations, viz. this, that the *intensity of the magnetic* force is greater in December than in June at *every* one of the Observatories, and, as far as it has been possible to observe, at every part of the surface of the earth. Now in December the earth is nearest to the Sun—in June it is most remote. The actual magnetic power of the *earth,* then, is greatest when the Sun is nearest. It *must* therefore derive some portion of its magnetic force from the direct action of the central body of our system. It would be interesting to determine the law of this increase of intensity, and to ascertain whether it follows that great law of gravity of the inverse square of the distance.

III. But, thirdly, a still more remarkable evidence is furnished by the knowledge of the existence of a periodic fluctuation in the magnetic disturbances, or, as they are sometimes called, *magnetic storms.* When the magnetic Observatories were first established in 1840, it was known that the needle is liable to sudden and capricious affections, and these affections, oftentimes considerable in amount, and rapidly changing, occurred at widely different positions, generally at the same moment of absolute time. It was supposed that there was a connexion of some kind between these disturbances and the *aurora borealis,* because on many occasions of these disturbances there had occurred simultaneously brilliant displays of auroral phenomena. But the observations show clearly that these irregular disturbances exhibit periodic laws of consistent and regular recurrence, and these laws depend on solar hours and solar months. And further, General Sabine has ascertained that the relative *frequency* and relative aggregate *value* of the disturbances present a regular *decennial* cycle, increasing progressively for five years, when they reach a maximum, and then decreasing. Thus, in 1843, the disturbances presented a minimum result; they increased in frequency and amount until 1848, when they reached an amount *three* times greater than in 1843, and from that time they began to decrease, probably until 1853.

The reduction of the observations made at Pekin furnish, as may be seen by the following Table, an interesting supplement to the conclusions derived from reductions of the Toronto and Hobarton observations (43).

Mean of Ratios of Magnetic Disturbances.

Hobarton and Toronto.

Year.	Numbers.	Values.
1843.	·60	·52
1844.	·78	·78
1845.	·72	·65
1846.	1·20	1·18
1847.	1·28	1·42
1848.	1·43	1·51
	Pekin.	
1852.		1·01
1853.		·82
1854.		·79
1855.		1·38

The correspondence of this decennial period with the periodic variations of the solar spots, as determined by the observations of Schwabe, to which I drew attention in the former part of this discourse, at once struck General Sabine, who was at the same time interested in the translation of Humboldt's 'Kosmos,' in which the labours of Schwabe were for the first time made public.

IV. Further, this decennial cycle is found to exist not only in the magnetic disturbances, but the same periodic fluctuation is to be observed in every one of the three magnetic elements, viz. the *declination*, the *inclination*, and the *total force**. In one of these elements, viz. that of the *declination* (44), the same law of periodicity was observed by Lamont previous to the discovery by Sabine; but it was not made known, nor was it connected with the periodicity of the spots of the Sun. But Sabine has established the existence of the law, not only from the discussion of the observations during the limited period of the operation of the magnetic Observatories, but by examining the rich mass of observations left by Arago (more than 52,000 in number, extending from 1821 to 1830), he has obtained a precise verification of the decennial magnetic period. The following Table exhibits the figures from which the law is derived:—

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* The meaning of the term Declination has been explained. "Inclination" expresses the position which a needle accurately balanced before magnetization will assume after it is magnetized when placed in the plane of the declination needle, or in the magnetic meridian. This used to be called the *Dip*.

The actual terrestrial magnetic force is continually varying. For modes of estimating this, see Nichol's Cyclopædia, art. "Magnetism, Terrestrial."

Mean Diurnal Range of Declination (Paris). Observations of Arago reduced by Sabine.

Years.	Mean.	Years.	Mean.
1821.	9′ 05″·9	1826.	9′ 45″·7
1822.	8 49·7	1827.	11 18·6
1823.	8 09·4	1828.	11 36·2
1824.	8 12·0	1829.	13 43·7
1825.	9 40·1	1830.	12 23·7

The subjoined Table presents also a similar law with regard to the Solar Diurnal Variation of the same element:—

Solar Diurnal Variation of the Declination.

Years.	Hobarton.	Toronto.	St. Helena.
1841.	6′·12	7′·74	2′·64
1842.	5·43	6·61	2·74
1843.	5·17	6·25	2·55
1844.	5·39	6·67	2·81
1845.	5·72	6·66	3·08
1846.	6·00	7·11	2·78
1847.	6·34	7·61	3·37
1848.	7·60	8·05	3·48
1849.	7·20	8·49	3·68
1850.	7·39	7·90	
1851.	6·13	7·52	
1852.	6·74		
1853.	6·22		
1854.	5·71		

These Tables are extracts from the Tables given by Sabine in the Transactions of the Royal Society, and from the preface of the just published volume of the St. Helena Observations. The original papers contain fuller tables, but these are sufficient to point out the maximum in the years 1828 and 1848; and when it is added that it appears from the Göttingen observations that there was a maximum effect in 1837, we have as full a verification of the law as can be expected. The Tables also point out 1833, 1843, and 1853 to have been years of minima.

V. Once more: the connexion between magnetic disturbances and the condition of the surface of the Sun receives a very remarkable support from the records of the magnetic needles in the Kew Observatory on the 1st of last September. On that day (as I mentioned when on the subject of the Solar Spots) Mr. Carrington and Mr. Hodgson witnessed one of those extraordinary outbursts of light in a large spot. Mr. Carrington first saw this "not 15″ from 11^h 18^m Greenwich time;" it disappeared at 11^h 23^m.

Now all the three self-recording instruments (45) in the basement of the Kew Observatory, from which all solar light is carefully excluded, were, as the photographs attest, agitated on that same morning from 11^h 15^m to 11^h 25^m. All the three were simultaneously affected, and most so for the first three minutes of time. The amount of deviation of the declination needle was rather more than 13′ westerly.

This is (it may be said) only one instance of the agitation of the needles simultaneous with an extraordinary action upon the surface of the Sun; but it is an instance of the greatest value when taken in connexion with the facts which are obtained by the observations which have been described.

It is only of late years (comparatively speaking) that the self-recording process for the magnetic needles has been made so perfect. Still more recent is the hypothesis of a connexion between the condition of the solar surface and the magnetism of the earth.

M. Wolff (whose formula for the recurrence of the spots, as depending upon the position of the planets Venus, the Earth, Jupiter, and Saturn, I alluded to before) has proposed (46) a formula for the magnetic declination as dependent on the observations of the spots; and he suggests further, that probably very shortly the variations of all the three magnetic elements may be similarly expressed, as functions of the spots.

Mr. Broun, in a paper transmitted to the Royal Society in the spring of this present year (47), conceives that he has established that the magnetic intensity of the earth obeys a law depending on the Sun's rotation on its axis. Such a conclusion would seem probable from our previous considerations; but this at least is certain, that the great central body of our system exerts a magnetic influence, not *indirectly* through the production of heat, but *directly* by some inherent power distinct from heat. The study then of the phenomena of magnetism presents a special interest, because in them we seem to have indications of every change that is occurring upon the surface of the Sun, and possibly some intimations as to its interior condition. In what direction further investigations may point it is impossible to say; but many lines open out before us, when we mark how the magnetic needle becomes a record of the agitations which are taking place upon the centre of our system.

It is to be regretted by every friend of science, that the observations have not been continued at the various Observatories; and especially that our Government has not been able to find means for acceding to the request made by this Association through His Royal Highness our late President, and by the President of the Royal Society, for establishing an Observatory at Vancouver's Island (48).

It is only a short step from what has been said, to infer the existence of the same decennial cycle in the recurrence of auroral phenomena. Cassini appears to have remarked a relation between the greater frequency of the aurora and the epochs of the greatest solar spots. But Mairan extended his observations to the recurrence of the aurora at those seasons of the year at which the zodiacal light is most visible, viz. at the Equinoxes; and further, he connected with the aurora the magnetic perturbations (49).

The observations made at Dunse by Mr. Stevenson, which are given in the Table (50), seem to indi-

Auroræ seen at Dunse (W. Stevenson).

Year.	Number.	Year.	Number.
1838.	27	1849.	9
1839.	38	1850.	4
1840.	43	1851.	5
1841.	42	1852.	14
1842.	9	1853.	15
1843.	10	1854.	17
1844.	13	1855.	10
1845.	10	1856.	5
1846.	16	1857.	6
1847.	30	1858.	15
1848.	19+	1859.	25

cate, quite as strongly as can be expected, the existence of the same decennial cycle. There is not a perfect accordance; nor indeed is such to be expected, for as yet there have been no perfect records of auroral appearances. The observations of Mr. Stevenson point to a maximum in 1839, and again in 1848. The number observed in that year were only 19; but Mr. Stevenson was absent from home during the best months of that year, and has no doubt that 1849 would, if it had been accurately noted, have given a maximum. Again, we have a maximum in 1859; so that there is a manifest tendency to the 10 years' cycle. At the same time, let it be remembered that many auroral phenomena might have been displayed which were not recorded.

There are other Tables of auroral phenomena published by M. Quetelet and by Hansteen, which do not confirm this law so thoroughly; but such Tables are obviously incomplete, because, first of all, they give only that which was seen at a certain period of the night, for example, at 9 P.M.; and secondly, the observations ought obviously to be made in high latitudes, probably higher than those of Mr. Stevenson (51).

But to bring these remarks to a conclusion. We have, as it will have been seen, much to learn—perhaps much more than it will be given to man to learn in this state of our existence—concerning the condition of the great luminary of our world. We are as yet ignorant of the way in which its perpetual fountains of heat and light are so continually supplied, of the effects which those streams are producing as they quiver in the apparently barren fields through which the bodies of this our system describe their circuits, or in the wider regions of space. We are ignorant of these and many other unceasing operations; but as we exercise our faculties upon them, this truth seems to come out more and more strongly, that the Creator has made nothing in vain; no particle of matter is destroyed; no force, no motion is lost; every vibration of light, every wave of the subtle ether has an effect and a record of itself somewhere. The photograph now retains that which seemed lately to be a transient image. Pictures make their trace upon a surface of glass, invisible except when revived by the soft moist breathing. Physiologists speak of impressions on the brain, which are brought out like the latent picture, long after they have been made. Nothing is really absorbed, nothing lost in nature;

every cause has its equivalent effect, every force its own exact result. And this suggests a thought which is not otherwise than most fitting to notice in this place. If every motion of the luminiferous ether has its effect and abiding record, may not every vibration of the sound-bearing air have its effect and record too? May not every word we speak have its effect upon some listening ear and recording mind,—an effect and a record far more difficult for us to trace than the effect of the Sunbeam, but not unobserved or unrecorded by Him who created nothing in vain?

NOTES.

(1) Whewell's History of Inductive Sciences, Additions to vol. i. p. 7.

(2) This Table is selected from the best authorities within reach. There is not any very precise agreement amongst astronomers as to the progressive motion in space. The reader may be referred for information on this subject to Herschel, Philosophical Transactions, 1783; Humboldt's Kosmos, vol. i. p. 134, and Note 101, Sabine's Translation. There is a recent paper on the Proper Motion of the Sun by the Astronomer Royal, in the Monthly Papers of the Royal Astronomical Society, 1859.

(3) Encyclopædia Metropolitana, art. "Astronomy," vol. iii. p. 493.

(4) Humboldt's Kosmos, vol. ii. p. 319; and vol. iii. p. 272.

(5) On this question see a Memoir by the late Professor Rigaud, published as a Supplement to Bradley's Miscellaneous Works, Oxford, 1833. Harriot's papers, preserved at Petworth, are then examined, p. 38 *et seq.*; and a *facsimile* of Harriot's original sketch, with the dates, is given at the end. This question is fully and interestingly examined in Brewster's 'Martyrs of Science,' Life of Galileo, p. 37, &c.

(6) Humboldt, vol. iii. p. 274, and Nichol's Cyclopædia

of Physical Science, art. 'Sun,' where the claims of Wilson as an early observer are maintained.

(7) Humboldt, *ut supra*.

(8) Humboldt, and Sir W. Herschel's Outlines of Astronomy, chap. vi. edit. 5th, from which much has been gleaned.

(9) Young's Lectures on Natural Philosophy, Lecture XLII.

(10) Humboldt, vol. iii. p. 278, and note.

(11) Outlines, p. 245. Professor Piazzi Smyth attempted to assign a very different origin to the red prominences in a paper read before the Association in 1852. He endeavoured to make them visible on ordinary occasions by imitating the eclipse experimentally. By variation of the experiment, somewhat similar effects were obtained, and these seem to indicate a diffractive origin for the phenomena in question.

(12) This was first described by Mr. Dawes to the Royal Astronomical Society, in a paper read April 7, 1852, and which is printed in the 'Proceedings.' The same paper describes the remarkable rotation of the spot seen in January 1852.

(13) See Monthly Papers, Royal Astronomical Society, December 1859.

(14) Comptes Rendus, April 1858 and 1859, p. 79.

(15) Comptes Rendus, especially February 1858, &c.

(16) Monthly Papers, Royal Astronomical Society, November 1859. Mr. Hodgson describes this outburst as equal in brilliancy to α Lyræ when seen through a large telescope with low power. Mr. Birt observed a very remarkable group on February 23, 1859, with two luminous patches exhibiting a fluctuating character, undergoing

changes of configuration; a diagram is given in the Monthly Papers of the Royal Astronomical Society, p. 183. Very beautiful delineations of spots, seen from August 1859, have been made by the Rev. F. Howlett, and communicated to the Royal Astronomical Society by Sir J. Herschel, who also deposited with the Society three MS. volumes of Observations made by M. Pastorff.

(17) Herschel's Outlines, p. 251; Humboldt's Kosmos, vol. iii. p. 280; Monthly Papers of the Royal Astronomical Society, November 1858.

(18) Monthly Papers of the Royal Astronomical Society, January 1859.

(19) Monthly Papers of the Royal Astronomical Society, March 1859.

(20) This Table is taken from Humboldt, vol. iii. p. 292, until 1850; for subsequent years, from the Astronomische Nachrichten for each year.

(21) Herschel's Outlines, p. 254; Humboldt, vol. iii. p. 277.

(22) Astronomische Nachrichten, No. 638; Humboldt, vol. iii. p. 293.

(23) Herschel's Outlines, p. 258.

(24) See Transactions of the Royal Society of Edinburgh, vol. xxi. 'On the Mechanical Energies of the Solar System,' by Professor W. Thomson, of Glasgow. This most interesting paper has been made much use of in this Discourse.

(25) Comptes Rendus, 1854, pp. 643, 883.

(26) Outlines, p. 664.

(27) March 1860, and Philosophical Magazine for May 1860, p. 338.

(28) Monthly Papers of the Royal Astronomical Society for January 1860.

(29) Popular Physical Astronomy. By Daniel Vaughan, Cincinnati, U.S., p. 93. There are extracts from this work in the volume of the British Association for 1858, in the Report on Luminous Meteors, p. 155. Mr. Vaughan also communicated some of his views to the Association in 1857, Sectional Proceedings, p. 42.

(30) Comptes Rendus.

(31) Curiosities of Science, p. 61.

(32) Kosmos, vol. i. p. 37, vol. ii. p. 329, and especially vol. iii. p. 284; and the notes to this last passage, and on page 286.

(33) Kosmos, vol. iii. p. 285, and Outlines; note to article 387; also article 393, and note.

(34) Kosmos, note, 483, vol. iii.; and Comptes Rendus for 1836, p. 576.

(35) Report of 1838.

(36) Transactions of the Royal Society, 1845, &c., especially 1857, 1860.

(37) Report for 1854, from which much has been borrowed.

(38) It has been stated that the diurnal variation presents a double progression with two maxima and two minima, the turning hours being six hours apart. The curve has also been represented by a formula of two terms, one involving the sine of the hour angle, and the other the sine of twice that angle. See Nichol's 'Cyclopædia,' the article in which is a translation of a paper of Secchi's, published in 1854 in the 'Correspondenza Scientifica' in Rome. This view has been adopted in the third volume of M. de la Rive's 'Traité d'Electricité.' But Sabine has clearly estsblished that his opinion, expressed in 1845, is the more correct. This opinion is fully brought out in a

paper in the 'Proceedings of the Royal Society,' vol. x. p. 360.

(39) Sabine, Report at Liverpool, 1854.

(40) St. Helena Observations, Preface, and Royal Society Proceedings, vol. x. *ut supra.* The observations at Pekin were made by Chinese observers, under the able superintendence of M. Scatchkoff, attached to the Russian embassy, and were continued for three years and ten months, from January 1, 1852, to October 31, 1855; and published by our distinguished foreign member, M. Kupffer, in the volumes of the 'Annales de l'Observatoire Physique Central de Russie.'

(41) This Plate is copied from the St. Helena Observations, and the Royal Society Proceedings.

(42) Makerstoun Observations, 1845, &c.

(43) Sabine, Royal Society Proceedings, and St. Helena Observations, Preface; Kosmos, vol. iv. p. 419.

(44) Report at Liverpool, 1854.

(45) These are the three magnets which indicate the Declination, the horizontal, and the vertical Force. Their motions are recorded by photography. A description of the instruments and the necessary arrangements is given in the Report of the British Association for 1859, p. 200, &c.

(46) Comptes Rendus, 1859.

(47) Royal Society Proceedings, May 1860.

(48) See Report of Kew Committee, presented to Oxford Meeting.

(49) Mairan's Works, p. 199; Kosmos, vol. iii.; Secchi on the Periodical Variations of Terrestrial Magnetism; Phil. Mag. for November 1854 and January 1855.

(50) This Table was given down to 1849 in the 'Proceed-

ings of the Royal Society' for March 1853. The subsequent part has been kindly supplied by Mr. Stevenson.

(51) Reference ought to be made to the observations at Point Barrow, on the shores of the Polar Sea, by Captain Maguire and the officers of Her Majesty's ship 'Plover,' from the summer of 1852 to the summer of 1854. The observations on the magnetic disturbances and the appearance of the auroræ confirm what is stated. A brief account may be seen in the communication made by General Sabine to the British Association at Dublin in 1857. See Report of Sectional Proceedings.

APPENDIX.

ECLIPSE OF THE SUN, JULY 18, 1860.

The labours of the scientific observers who went to Spain to watch the phenomena of this eclipse seem to have been eminently successful. Some few (as, for instance, Mr. Lowe) appear to have lost the important period of totality by the interposition of clouds; but others were more favoured. There is some little difference in the reports which have been as yet published; and we must wait with interest for the volume which is announced for authoritative accounts of the observations.

It is remarkable that several of those who were watching any change do not appear to have seen any thing like the red prominences to which so much of interest is attached. The correspondent of the 'Morning Post' says that none of the party with whom he was associated could discover any thing of the kind, although they especially looked for them. He describes, however, with great vividness, the brightness of the corona, and the flashes of light which appeared to dart out from behind the surface of the moon.

Mr. Thompson, formerly Observer in the University of Dublin, in a letter written to the 'Times,' from Tudela, gives a very interesting account of the diminution of light, and of the glory which surrounded the sun, but he says nothing of red flames or apparent prominences.

After describing the effects upon the surrounding scenery, he thus continues:—

"On looking upward from these I found that the sun had already disappeared, and that I had missed the formation of the corona. The black circle of the moon was already surrounded by this crown of glory; two stars shone brightly a few degrees from the sun; and so magnificent was the spectacle above, so glorious the spectacle below, that I could not help looking for a few moments from the one to the other. A bright light, I think of a greenish yellow colour, skirted the horizontal sky; and the banks of cumuli shone with a brilliant glow. The darkness was not intense; the light from the corona and the distant refractions far surpassed the brightest moonlight. It would have been easy to read the smallest type.

"I now looked at the corona. It was not of uniform breadth, but generally about half the moon's diameter, while long beams of light issued forth in several directions. The longest, about 10° below the east side of the sun, was considerably longer than the moon's diameter, if I can trust my memory, after the totality was passed.

"The beam next in length was not far from the lowest point of the sun's vertical diameter, a few degrees to the west; and this beam, as it approached the sun, appeared to curve upwards, and to join another beam which was thrown off about 45° below the eastern edge of the sun. For a few moments these two beams formed a distinct crescent, with its convex edge nearly touching the sun; otherwise the beams remained unchanged during the total eclipse; but this crescent was not evident during the whole time.

"Another of the longer beams was thrown off from a point about 30° east of the top of the vertical diameter.

"I also observed within the halo three darker beams, much shorter than the breadth of the corona. One of these issued from the central point of the crescent I have described. The other two were, I believe, near the top of the eastern edge, but of this I speak from recollection, and not with confidence.

"While I was observing these beams the edge of the Sun suddenly reappeared, about 9½ minutes past 3, and the first instantaneous burst of returning light was very impressive. I now observed intently the disappearance of the corona, and can say with confidence that it did not disappear, but was gradually rendered invisible by the increasing intensity of the Sun's light. I could perceive it gradually diminishing in breadth, till I could no longer observe the Sun without protection to the eyes."

I am favoured, however, by Mr. Warren De la Rue, with the following notice, which puts the appearance of the red prominences beyond all doubt.

Mr. De la Rue thus writes:—

"My own station was Rivabellosa, about three miles from Miranda, about N. lat. 42° 42′, W. long. $11^m. 40^s.$, and 1572 feet above the mean sea-level. I obtained, with the aid of my four assistants, no less than thirty-one photographs of the Sun during the eclipse, and two of them during the totality. During the eclipse I observed the phenomena with a splendid 3-inch telescope made by Dallmeyer (Ross's son-in-law) of 19 Bloomsbury Street.

"Both the photographs and eye observations make evident the following facts:—

"That the luminous prominences are of far greater brilliancy than the corona;

"That the prominences undoubtedly belong to the Sun, this being rendered evident from the circumstance of the luminous prominences first seen on the east gradually diminishing in height as the moon glided along, while others on the west, scarcely visible at first, were observed to project more and more, while new prominences came into view.

"The prominences could not be called red: they varied in colour, were exceedingly brilliant; but two exhibited a decided, but pale, rose tint. One prominence, 1′·5 long, was quite detached.

"My plates were only 6 inches square; and the sun's image being 4 inches in diameter, I could not get pictures of the corona; but it has left its trace as far as the plate would allow.

"I could give only a cursory glance at the corona. It did not extend so far as I had thought it would have done. It might have been circumscribed generally by a radius 1·8, the moon's radius being 1; but there were outlying streamers."

Mr. Lowe gives also the following account of observations made by Mr. Thompson, Master of Her Majesty's ship 'Himalaya,' which was most liberally granted by the Government to convey the party of observers to and from Spain:—

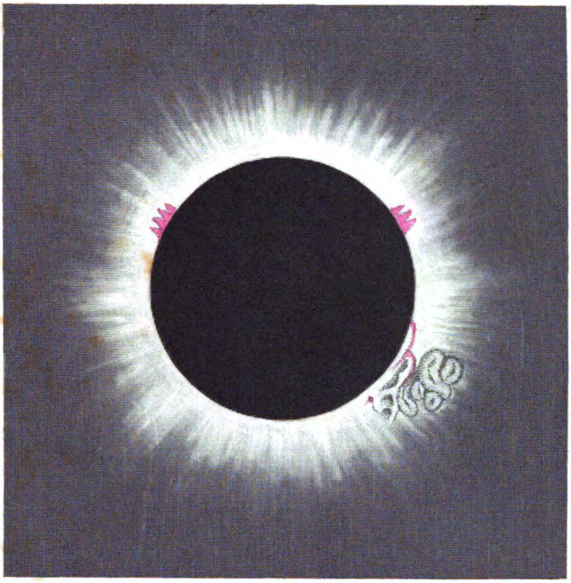
"Totality commenced at 2h. 52m. 55s., when prominences were visible, one on the west and two on the east, of a bright lurid lake colour, followed by the corona shooting out on the east of the sun in two forked tongues. The colour of the corona was white, darting outwards. Towards the end of totality another prominence was noticed on the west side of the sun, of the same colour as those first seen; and below this a most beautiful collection, as of golden beads closely strung together, shone out, extending to the lowest part of the western limit of the sun. The stars numbered 7 and 8 in Mr. Hind's map were distinctly visible in the telescope. The cusps of the sun were rounded before and after totality, and the prominences were lurid and well-defined. A very considerable variation of the compass took place during the eclipse."

The fact of the appearance of the red flames cannot, then, be questioned. Probably those who did not see them were not furnished with instruments of sufficient power, or their attention was distracted by other phenomena. It must be remembered that the duration of such an eclipse is very brief, the phenomena are changing continually, and an unpractised eye necessarily loses much. It is impossible also for every observer to see all. Those are most to be depended upon who limit their attention to one or two particulars. The observations of Mr. Warren De la Rue, supported as they are by the sure evidence of photographs, are of the greatest value and authority.

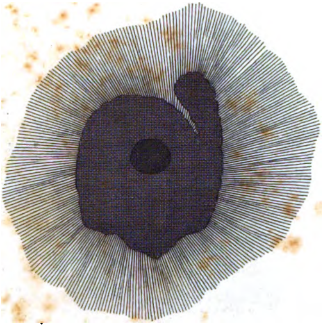
The remark at the close of the account furnished by Mr. Thompson, viz. "that there was a considerable variation of the compass during the eclipse," struck me on first reading as important; but this variation could not have been due to any influence of the sun or moon. I have ascertained from Mr. Stewart, of the Kew Observatory, that the needles there were perfectly steady during the whole time; nor were they disturbed in the slightest degree during the eclipse of 1858.

The 'Himalaya' is an iron ship; and consequently we must not be astonished at affections in the compasses. They may occur from changes of the ship's position, or from causes much nearer than the action of the sun and moon.

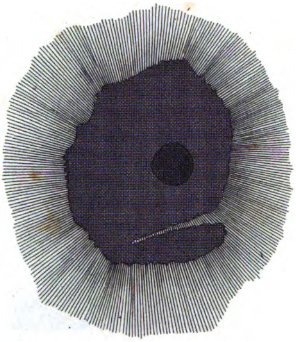
Plate.1.



Jan.17.



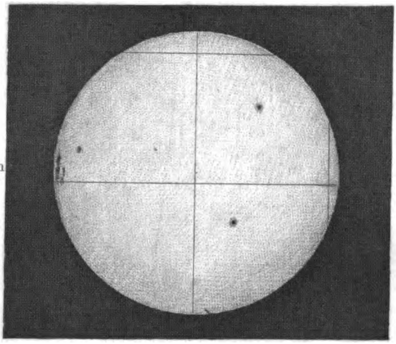
Jan. 23.



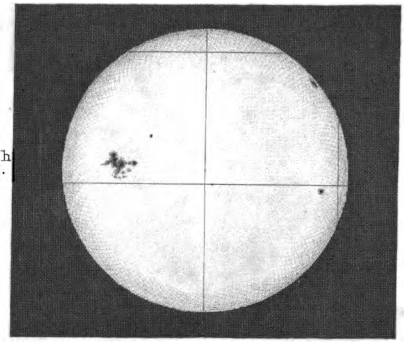
J.Basire sc.

Plate II

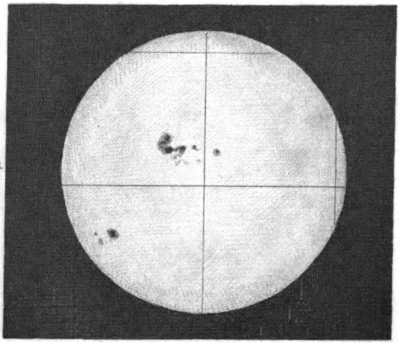
1859. Aug. 25.$^{\mathrm{d}}$ $3\frac{1}{2}^{\mathrm{h}}$



1859. Aug. 28.$^{\mathrm{d}}$ $0\frac{1}{2}^{\mathrm{h}}$



1859. Aug. 30.$^{\mathrm{d}}$ $5\frac{1}{4}^{\mathrm{h}}$



J. Basire sc.

Diurnal Variation of the Declination.

Fig. 1.

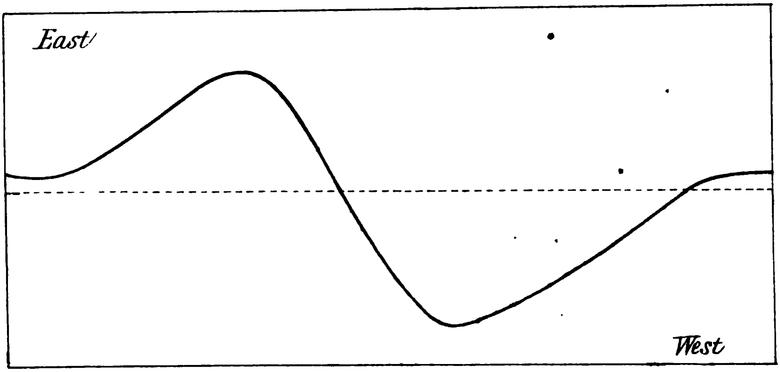


Fig: 2.

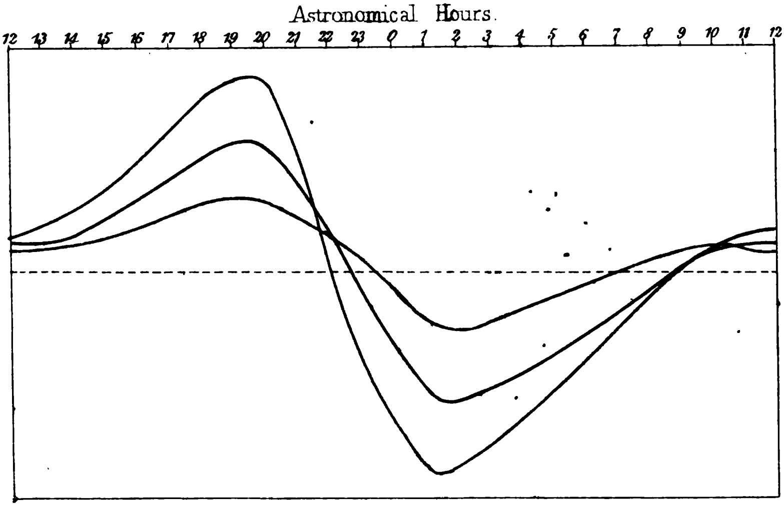


Plate IV.

Solar diurnal Variation of the Magnetic declination.
Semi annual inequality.